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Non-Destructive Investigation of the Fragment of Mirror (6th-4th Centuries BCE) from the Necropolis Volna 1on the Taman Peninsula by Neutron Resonance Capture Analysis

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Neutron Resonance Capture Analysis (NRCA) is known as non-destructive method. The use of neutrons, a highly penetrating particle, with resonance energy, allows one to investigate archeological objects without damaging. NRCA is based on the registration of neutron resonances in radiative capture and the measurement of the yield of reaction products in these resonances. We have applied the method for the analysis of several archeological objects from the necropolis Volna 1. In this paper, we concentrate on a study of fragments of mirrors.

1. INTRODUCTION

In this paper the application of Neutron Resonance Capture Analysis (NRCA) will be discussed. Neutron Resonance Capture Analysis (NRCA) is applied to determine the elemental composition of objects [1]. The method is non-destructive, doesn't require special preparation of samples, and allows measuring the bulk composition of objects. All these analysis characteristics listed are useful for the investigation of archeological samples. The method of NRCA is currently being developed at the Frank Laboratory of Neutron Physics (FLNP) [2, 3]. It is based on the registration of neutron resonances and the measurement of reaction products yield in these resonances.

In this paper, we describe the application of NRCA for the investigation of an archeological object transferred to the FLNP by the Institute of Archeology of the Russian Academy of Sciences.

In 2016-2018 a Sochi Expedition group of Institute of Archaeology of the Russian Academy of Sciences under the leadership Roman A. Mimokhod conducted excavations of an antique town soil necropolis Volna 1 on the Taman Peninsula [4]. The burial ground Volna-1 is an important monument for studying of a problem of Greek-Barbarian relations on the territory of the borderland – the Northern Black Sea region, the clash and interaction of two different ethnocultural layers of the population. During the excavation of the burial ground, a representative collection of archaeological material was obtained, dated within the 6th-4th centuries BCE. Rather rare objects were found in the burials: an artificial limb, musical instruments (cithara, harp), a bronze Corinthian helmet, and fragments of mirrors.

The mirror has high vertical ledges, presumably belong to the Borysthenitic type of mirrors (Fig.1). The handle is lost, the remains of the fastening are preserved on the mirror. The metal of the mirror is degraded to a large extent, it is not possible to restore the height of the side and the design of the fastening. Analysis of the elemental composition by the XRF method is difficult. In this regard, data on the elemental composition obtained by the NRCA method are of great importance.

Fig. 1. The fragment of mirror (6th-4th centuries BCE).

2. EXPERIMENT

The sample was irradiated with neutrons at the resonance neutron source IREN to obtain time-of-flight spectra of (n,γ) reactions. The main part of the IREN facility is the linear electron accelerator LUE-200 with a non-multiplying neutronproducing target of W(90%)+Ni+Fe-alloy. The detailed description and parameters of the facility can be found in [5-7].

The measurements were carried out at a 58.6-m flight path of IREN beamline 3. To obtain time-of-flight spectra the sample was placed inside the large liquid scintillation detector. The START signal is generated by the synchronizer of the IREN facility, the STOP signals come from the detector. The measurements of the investigated sample lasted about 37 h. The resonance energies were determined by the following formula:

$$E = \frac{5227L^2}{t^2}, \qquad (1)$$

where t – time of flight in microseconds, L – flight path in meters, E – kinetic energy of aneutron in eV. The resonances of copper and tin were identified on the time-of-flight spectrum (Fig.2) based on the values of resonance energies in [8, 9].

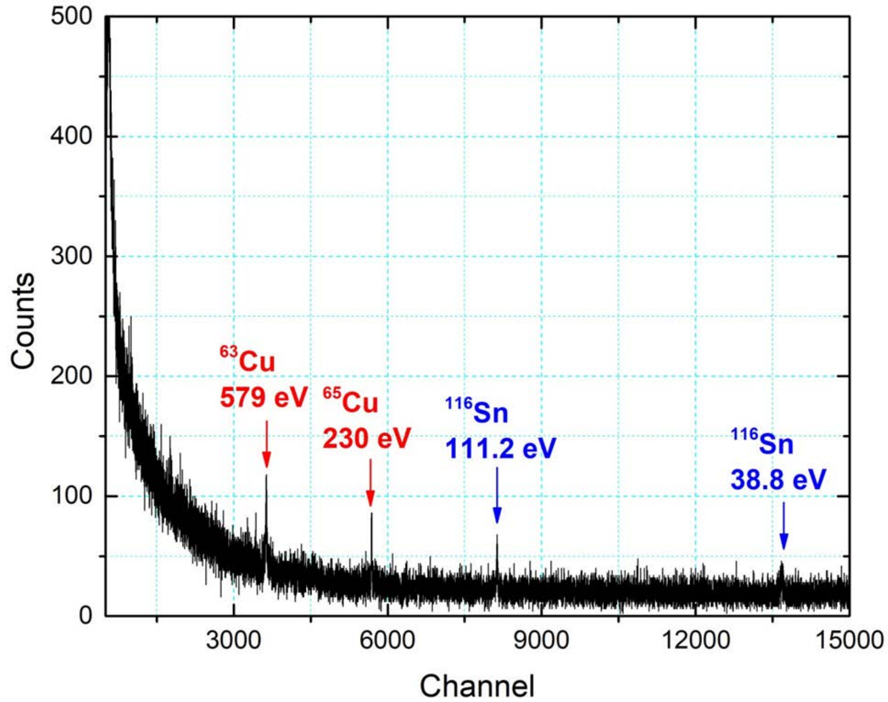

Fig. 2. The part of reactions time-of-flight spectrum (n,γ) obtained in measurements on the fragment of mirror. The time channel width is 50 ns.

The measurements with standard samples of identified elements were made in addition to the measurement with the investigated sample. Parts of time-of-flight spectra of (n,γ) reactions on the material of standard copper and tin samples are shown in Figure 3, 4.

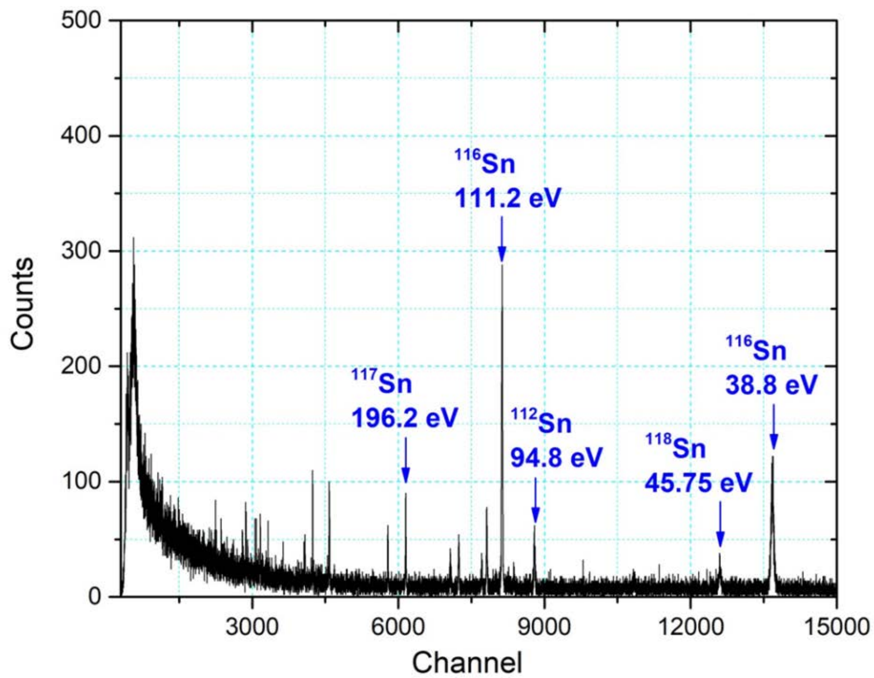

Fig. 3. The part of reactions time-of-flight spectrum (n,γ) of tin standard sample. The time channel width is 50 ns.

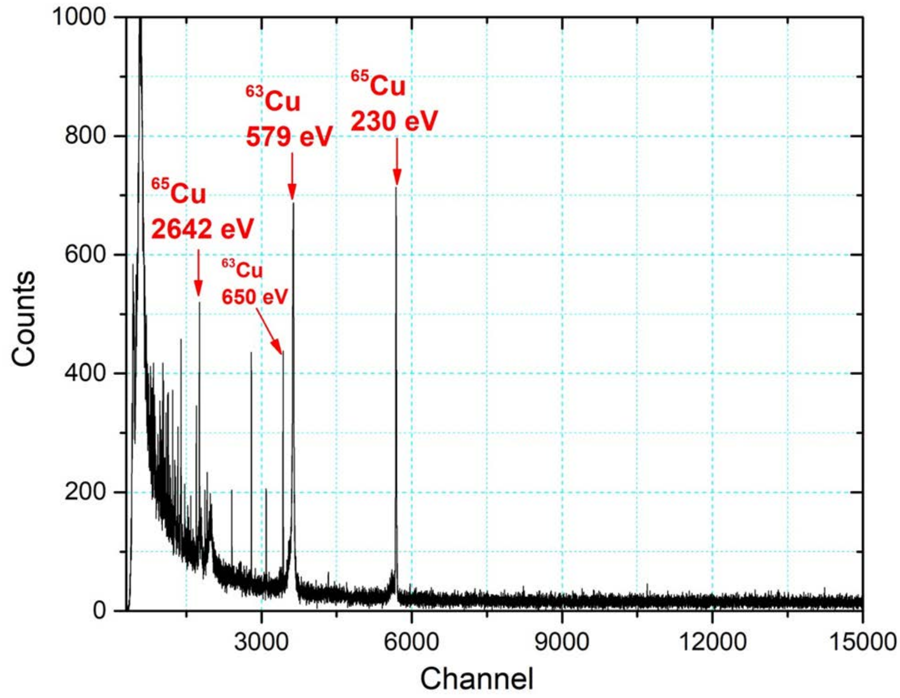

Fig. 4. The part of reactions time-of-flight spectrum (n,γ) of copper standard sample. The time channel width is 50 ns.

3. DATA ANALYSIS AND RESULTS

The number of element nuclei in the sample was determined by using the number of counts in resonances. Two resonances of tin (38.8 eV, 111.2 eV), two resonances of copper (230 eV, 579 eV) were selected during the experimental data analysis. The sum of detector counts in a resonance is:

$$\sum N = f(E_0) \cdot S \cdot t \cdot \varepsilon_\gamma \cdot \frac{\Gamma_\gamma}{\Gamma} A \qquad (2)$$

Where, $f(E_0)$ is the neutron flux density at the resonance energy E_0, S is the sample area, t is measuring time, ε_γ is the detection efficiency of the detector radiative capture, $\Gamma\gamma$, Γ are the radiative and total resonance widths.

$$A = \int_{E_1}^{E_2} [1 - \exp(n\sigma(E))] dE \qquad (3)$$

is a resonance area under the transmission curve, where E_1, E_2 – initial and final values of energy range near resonance, $\sigma(E)$ is the total cross section at this energy with Doppler broadening, n is the number of isotope nuclei per unit area.

As can be seen from (3), the value A includes the required parameter – the number of isotope nuclei per unit area. The procedure for extracting this parameter and a description of the use of additional measurements with standard samples are described in [2]. The analysis results are presented in Table 1.

Table 1. The results of measurements of the fragment of mirror by the NRCA method

Element	**Massa, g**	**Weight, %**
Cu	16.76±0.98	89±5
Sn	1.06±0.22	5.6±1.2

4. CONCLUSION

The fragment of the mirror was found in the necropolis Volna 1 on the Taman Peninsula. The elemental and isotopic composition of the sample was determined by NRCA. The mass of the fragment of the mirror is 18.83 g. According the result of analysis the value of determine total elements mass coincides with the artifact mass within the margin of error. The result obtained allows us to be sure that during the manufacture of this mirror in the 6th-4th centuries BC. tin bronze was used with a tin content of up to 10%. These data are well extrapolated to the results of studies of Greek and Etruscan bronze mirrors, carried out by various methods of analysis. In this case, the NRCA method showed good results in the analysis of completely corroded objects, on which it is difficult to study the composition of the metal by other standard analysis methods.

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